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SUMMARY

An experimental program was conducted to study the damaging effects of tensile and compressive prestrains on the fatigue life of nickel-base, Inconel 718 superalloy at room temperature. To establish baseline fatigue behavior, virgin specimens with a solid uniform gage section were fatigued to failure under fully-reversed strain-control. Additional specimens were prestrained to 2, 5, and 10 percent (engineering strains) in the tensile direction and to 2 percent (engineering strain) in the compressive direction under stroke-control, and were subsequently fatigued to failure under fully-reversed strain-control. Experimental results are compared with estimates of remaining fatigue lives (after prestraining) using three life prediction approaches: i) the Linear Damage Rule, ii) the Linear Strain and Life Fraction Rule, and iii) the nonlinear Damage Curve Approach. The Smith-Watson-Topper parameter was used to estimate fatigue lives in the presence of mean stresses. Among the cumulative damage rules investigated, best remaining fatigue life predictions were obtained with the nonlinear Damage Curve Approach.

KEY WORDS: prestraining, metal fatigue, cumulative fatigue damage, mean stress, life prediction, nickel-base superalloy

NOMENCLATURE

a_1, a_2	Exponents in the Smith-Watson-Topper parameter-life relation
b, c	Exponents of axial elastic and inelastic strain range-life relations
e_t	Total prestrain
e_{in}	Inelastic strain offset after prestraining
n_1	Number of applied cycles at the first load level in a two load level fatigue test
n_2	Number of remaining cycles at the second load level in a two load level fatigue test
A_1, A_2	Coefficients in the Smith-Watson-Topper parameter-life relation
B,C	Coefficients of axial elastic and inelastic strain range-life relations
E	Elastic modulus
N_1	Fatigue life at the first load level in a two load level fatigue test
N_2	Fatigue life at the second load level in a two load level fatigue test
N_f	Cycles to failure
%RA	Percent reduction in area in a tensile test
Δ	Denotes range of the variable

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ε_e, ε_{in} Elastic and inelastic strain amplitudes
$\varepsilon_{in,P}$ True inelastic strain offset after prestraining, $\ln(1+e_{in})$
ε_f Ductility or true fracture strain in a tensile test, $-\ln(1-\%RA/100)$
ε_t Total strain amplitude
ν Frequency
σ Stress amplitude, $(\sigma_{max} - \sigma_{min})/2$
σ_m Mean stress, $(\sigma_{max} + \sigma_{min})/2$
σ_{max} Maximum stress in a cycle
σ_{min} Minimum stress in a cycle
σ_y 0.2 percent offset axial yield strength
σ_u Ultimate tensile strength

INTRODUCTION

Engineering components are commonly subjected to prestraining due to manufacturing processes (forming operations, straightening, etc.), unintentional overstrains (misuse, accidents, under designs, etc.), and intentional overstrains (proof-testing or autofrettage). All prestraining operations can potentially damage an engineering component due to surface roughening and microcracking and thus reduce the subsequent fatigue life of the component during actual service. However, the prestraining operations can be beneficial to the component and increase its subsequent fatigue life because of cold working (or hardening) within the critical regions of the component and generation of residual stresses with a sign opposite to that of service loading. For accurate fatigue life estimation of the engineering components, the damaging and beneficial effects of prestraining should be properly considered by the fatigue life prediction models.

The influence of prestraining on the fatigue behavior of the nickel-base superalloy, Inconel 718 (IN 718) was investigated by conducting fatigue tests at ambient laboratory conditions. Inconel 718 is used extensively as a structural material in the aerospace and power generation industries (refs. 1 to 4). The baseline fatigue behavior of IN 718 was determined by performing strain-controlled fatigue tests. Fatigue tests were subsequently conducted on specimens prestrained either in tension or compression. In all the prestrained tests development of significant mean stresses was observed. The fatigue lives of the prestrained specimens were estimated with three cumulative damage approaches, both with and without consideration of the effect of mean stress on fatigue life. For each of the six sets of life predictions, the estimated fatigue lives of the prestrained specimens were compared with those observed in the experiments.

Experimental Details

Material and Specimens.—Wrought bars of IN 718 (Aerospace Material Specification 5663D) with a diameter of 31.8 mm were purchased from the vendor. The composition of the superalloy is shown in table I. The following heat treatment was given to the superalloy by the manufacturer: i) Solution annealing at 954 °C for 1 hr and water quenching, ii) Aging at 718 °C for 8 hr followed by furnace cooling to 621°C, and iii) Aging at 621 °C for 10 hr. The as-received material contained equiaxed grains with an average grain size of 10 μm. The microstructure and the different phases observed in the as-received material were previously reported (ref. 5). IN 718 derives its strength mainly from an intermetallic phase, γ'', which precipitates coherently in the face-centered-cubic matrix with a volume fraction of about 15 to 20 percent (refs. 6 to 8). Two other intermetallic phases commonly observed in IN 718 are γ' (≈ 4%vol fraction) and δ (refs. 6 to 9). The γ' phase is also a coherent phase and contributes to the strength of IN 718 (ref. 8).

Solid, uniform gauge section test specimens with a diameter of 6.3 mm were manufactured from the IN 718 bars. All the test specimens were polished with the final polishing marks in the longitudinal direction. The following average room temperature tensile properties were exhibited by the as-received IN 718: i) σ_y, 1140 MPa; ii) σ_u, 1410 MPa; and iii) %RA, 43.3 (or ε_f, 0.567). At room temperature, IN 718 has high strength as well as moderate ductility, and both properties contribute to the fatigue resistance of the alloy.

Test System and Procedures.—All the specimens were tested at room temperature under ambient laboratory conditions. The test system consisted of a computer-controlled (ref. 10), servo-hydraulic test frame and an axial extensometer with a gauge length of 12.7 mm. Baseline fatigue tests were conducted under total axial strain control. Fully-reversed sinusoidal waveforms with frequencies ranging from 0.1 Hz (at higher strain ranges) to 1.0 Hz (at lower strain ranges) were used in these tests. In the baseline tests, before applying the full amplitude of the strain, a small fully-reversed elastic strain cycle ($\Delta\varepsilon_t = 0.25$ percent) was used to obtain the elastic modulus of IN 718. The full amplitude strain was then applied beginning with the tensile direction. Cyclic data in the baseline fatigue tests were acquired at logarithmic intervals and fatigue tests were continued until each test specimen separated into two pieces.

Fully-reversed fatigue tests were also conducted on specimens prestrained either in tension (to 2, 5, or 10 percent) or in compression (to 2 percent). Only the lowest prestrain level was used in compression to avoid buckling, which is possible (and was observed) at the higher magnitude prestrains in compression. Each specimen was prestrained under stroke-control with a limit imposed on the strain. After reaching the required strain limit, the specimen was unloaded to zero load under stroke control and the extensometer was removed and remounted on the specimen. Before starting the fatigue portion of the test, the extensometer was zeroed to reestablish the gauge length. In all the tests on prestrained specimens, cross-sectional areas of the specimens after prestraining were used to calculate stresses during the subsequent fatigue portions of the tests. Similar to the baseline fatigue tests, for all the prestrained specimens, the fatigue portion of the test was always initiated in the tensile direction. The cyclic data acquisition scheme and failure definition in these tests were the same as those employed in the baseline tests.

Fatigue Behavior

Baseline Tests.—The baseline fatigue data of IN 718 obtained from the near half-life hysteresis loops are shown in table II. The average value of the elastic modulus, obtained from the initial elastic strain cycle data of the baseline tests, for IN 718 is 216 GPa. The total strain range in each test was separated into elastic and inelastic strain ranges by using elastic modulus and the stress range (eq. (1)).

$$\begin{aligned} \Delta\varepsilon_t &= \Delta\varepsilon_e + \Delta\varepsilon_{in} \\ \Delta\varepsilon_e &= \Delta\sigma/E \\ \Delta\varepsilon_{in} &= \Delta\varepsilon_t - \Delta\sigma/E \end{aligned} \tag{1}$$

In all the baseline fatigue tests, IN 718 developed compressive mean stresses. However, magnitudes of these mean stresses were relatively small in comparison to the stress ranges in the baseline tests (table II). After the second cycle, cyclic softening was observed at all strain ranges in the baseline fatigue tests. Softening continued until failure in all the IN 718 specimens (ref. 11). The observed cyclic softening was due to "mechanical scrambling" of γ'' precipitates by dislocations in the deformation bands (ref. 5). Serrated flow was observed in the inelastic regions of the hysteresis loops in the high strain range tests. The observed serrated flow in IN 718 was attributed to a repetitive mechanism in which dislocations initially piled-up at the grain boundaries were relieved by the onset of plastic flow in the neighboring grains or twins (ref. 12).

Basquin (ref. 13) and Manson-Coffin (refs. 14 and 15) type of elastic and inelastic strain range versus fatigue life relations were computed by treating the logarithms of $\Delta\varepsilon_e$ and $\Delta\varepsilon_{in}$, respectively, as independent variables and logarithm of N_f as the dependent variable (eq. (2)). The total strain range versus fatigue life relation was obtained by adding the elastic and inelastic life relations (eq. (3)).

$$\begin{aligned} \Delta\varepsilon_e &= B\,(N_f)^b = 0.0146\,(N_f)^{-0.0547} \\ \Delta\varepsilon_{in} &= C\,(N_f)^c = 1.30\,(N_f)^{-0.629} \end{aligned} \tag{2}$$

$$\Delta\varepsilon_t = 0.0146(N_f)^{-0.0547} + 1.30(N_f)^{-0.629} \tag{3}$$

The elastic, inelastic, and total strain range versus fatigue life relations are shown in figure 1. The slope of the elastic life line for IN 718 (-0.0547) is very shallow compared that exhibited by most engineering alloys (-0.12). The fatigue life relation from the baseline tests was used to evaluate the influence of prestraining on the fatigue behavior of IN 718.

Prestrained Tests.—The prestrains imposed on the IN 718 specimens and data from the fatigue portions of the tests, obtained from near half-life hysteresis loops, are shown in table III. As in the case of the baseline tests, the total strain range was separated into elastic and inelastic parts by using equation (1). All the prestrained specimens developed significant mean stresses. In general near half-life, the specimens prestrained in tension exhibited tensile mean stresses and the specimens prestrained in compression developed compressive mean stresses with a few exceptions. In all tests on prestrained specimens, the mean stresses persisted until failure of the specimens (ref. 11).

Fatigue data on the prestrained specimens and the baseline fatigue life relation are plotted in figure 2. Prestraining has a detrimental effect on the fatigue life of IN 718 with a few exceptions. The detrimental effect of prestraining is larger at the lowest strain range tested and progressively decreases at higher strain ranges. At the lowest strain range, tensile prestraining reduced the life substantially, whereas compressive prestraining did not significantly influence fatigue life. Since specimens prestrained in tension and compression developed different mean stresses, some of the observed differences in fatigue lives might be due to mean stress effects. The role of mean stress on fatigue life of Inconel 718 is addressed later in the paper.

Life Estimation

Cumulative Damage Models.—Three cumulative damage models were used to estimate the fatigue lives of the prestrained specimens. They are i) the Linear Damage Rule (LDR), ii) the Linear Strain and Life Fraction Rule (LSLFR), and iii) Damage Curve Approach (DCA). The LDR of Palmgren (ref. 16), Langer (ref. 17), and Miner (ref. 18) is widely used in estimating fatigue life under variable amplitude fatigue loading and assumes that fatigue failure occurs when the summation of life fractions from different loadings reaches unity. For a two load-level test, the LDR is shown in equation (4).

$$\left(\frac{n_1}{N_1}\right) + \left(\frac{n_2}{N_2}\right) = 1 \tag{4}$$

The LSLFR is similar to the rule proposed by Burgreen (ref. 19) for thermal ratchetting during temperature cycling. This rule assumes that failure occurs in a prestrained specimen when the summation of the strain fraction and life fraction reaches unity (eq. (5)).

$$\left(\frac{\varepsilon_{in,P}}{\varepsilon_f}\right) + \left(\frac{n_2}{N_2}\right) = 1 \tag{5}$$

The DCA was developed by Manson and Halford (refs. 20 and 21) to overcome the load ordering effect that is commonly observed in cumulative fatigue damage tests. This rule assumes that the accumulation of fatigue damage occurs in a nonlinear fashion, and the degree of nonlinearity is a function of the ratio of fatigue lives corresponding to the lowest and the highest load levels. The DCA for a two load level fatigue test is shown in equation (6).

$$\left(\frac{n_1}{N_1}\right)^{\left(\frac{N_1}{N_2}\right)^{0.4}} + \left(\frac{n_2}{N_2}\right) = 1 \tag{6}$$

All the variables in equations 4 to 6 are defined in the nomenclature section. Note that in equaitons 4 to 6, the accumulation of fatigue damage is completely independent from the life relation that is necessary to establish the fatigue life at each load level.

Fatigue Life Estimation without Mean Stress Effects.—In estimating the fatigue lives of the prestrained IN 718 specimens initially the effect of mean stress on the fatigue life was not considered. In the case of the LDR and DCA the prestraining portion of the test was considered as a quarter cycle ($n_1 = 0.25$) with a strain range equal to twice the magnitude of the prestrain. Therefore, N_1 corresponding to this strain range was calculated with equation 3. In the case of the LSLFR the true inelastic strain offset after prestraining was used to compute the strain fraction in equation 5. In all the life prediction methods, N_2 corresponding to the fatigue portion of the tests was computed from equaiton 3 by using the $\Delta\varepsilon_t$ values listed in table III. The fatigue lives of the prestrained specimens (n_2) were then estimated with equations 4 to 6. The results are shown in figure 3 for all the cumulative damage models. The fatigue lives predicted by the LDR and the LSLFR were very similar and were unconservative by up to a factor of 20 compared to the experimentally observed fatigue lives. These unconservative predictions occurred mainly at the lowest strain range in tensile prestrained specimens, most of which developed large tensile mean stresses during the subsequent fatigue loading. The fatigue lives predicted by the DCA were significantly better than those by either the LDR or the LSLFR.

Fatigue Life Estimation with Mean Stress Effects.—The quantitative effect of mean stress (either tensile or compressive) on the fatigue life of the heat of IN 718 investigated in this study has, as yet, not been characterized. However, consideration of mean stress is necessary because tensile mean stress is usually detrimental to fatigue life whereas compressive mean stress might be beneficial. Korth (ref. 4) investigated the applicability of three mean stress models to IN 718 and reported that the parameter proposed by Smith, Watson, and Topper (ref. 22) most accurately described the behavior of this alloy. Therefore, an attempt was to made to include the effect of mean stress on fatigue life with the Smith-Watson-Topper parameter (SWT). A twin power-law relation was established between SWT and N_f with the baseline fatigue data (table II) for IN 718 (eq. (7)).

$$\begin{aligned} \sigma_{max}\varepsilon_t E &= A_1(N_f)^{a_1} + A_2(N_f)^{a_2} \\ \sigma_{max}\varepsilon_t E &= 2.52\times10^6(N_f)^{-0.114} + 2.14\times10^8(N_f)^{-0.683} \end{aligned} \tag{7}$$

Equation (7) and the baseline fatigue data are shown in figure 4. The SWT was then employed to estimate the fatigue life, N_2 corresponding to the fatigue loading after prestraining. The computed N_2 values contain the influence of mean stresses because in SWT the mean stress effect is included through the maximum stress in the hysteresis loop (eq. (7)).

Fatigue lives of the prestrained IN 718 specimens were computed with equations (4) to (6). For all the life prediction models, the damage from the prestraining was estimated as described earlier. Comparisons of the predicted and observed fatigue lives are shown in figure 5. As noted earlier, predictions by the LDR and LSLFR were very similar. At the lowest strain range, the predicted fatigue lives by these two models were unconservative by up to two orders of magnitude compared to the observed fatigue lives. All methods overestimated the fatigue lives of the lowest strain range tests on compressively prestrained specimens. Among the cumulative damage methods investigated, the best predictions were obtained with the DCA method.

DISCUSSION

The fatigue life of IN 718 was influenced by both the magnitude and direction of prestraining (fig. 2). In general, tensile prestraining was detrimental at all the strain ranges investigated. Compressive prestraining reduced fatigue lives marginally at the higher strain ranges, whereas at the lowest strain range it did not affect the fatigue life. While investigating the deformation and damage mechanisms in IN 718, Kalluri et al. (ref. 5) noted that in the 10 percent tensile prestrained specimen fatigued subsequently at the lowest strain range, deformation was very inhomogeneous and was confined to a few well-defined slip bands. At the lowest strain range, deformation during the fatigue loading was confined to the deformation bands activated during the tensile prestrain, whereas at the higher strain ranges additional deformation bands were activated during fatigue. The inhomogeneous deformation noted at the lowest strain range can increase stress concentration at the intersections of slip bands and grain boundaries and can lead to microcrack initiation. In addition, tensile prestraining can induce microscopic slip steps on the surface of the specimen and these slip steps can also serve as microcrack initiation sites during the subsequent fatigue loading. Both of these mechanisms tend to lower the fatigue lives of prestrained specimens due to a reduction in the crack initiation portion of their cyclic lives. Even though the proposed mechanisms can explain the observed reduction in fatigue life due to tensile prestraining they can not explain the apparent lack of influence of compressive prestraining on the fatigue life at the lowest strain range. The deformation and damage mechanisms in specimens subjected to compressive prestraining followed by fatigue remain to be investigated.

The observed fatigue lives of the prestrained specimens indicated that significantly detrimental effects of tensile prestraining were experienced mainly in the low strain range, high cycle fatigue regime (fig. 2). Fatigue life predictions by the nonlinear DCA, when the effect of mean stress on fatigue life was not considered, were more accurate than those by the LDR or the LSLFR, especially in the low strain range, high cycle fatigue regime (fig. 3). These results suggest that the damages due to prestraining and the subsequent fatigue loading accumulate in a nonlinear manner. In the low strain range, high cycle fatigue regime, tensile prestraining substantially lowers the subsequent fatigue life because N_1 and N_2 in equation 6 are significantly different in this regime. In the high strain range, low cycle fatigue regime, N_1 and N_2 are of the same order of magnitude and as a result tensile prestraining does not have a significant influence on the subsequent fatigue life. At the lowest strain range, among the tensile prestrained specimens, the highest and lowest average fatigue lives were observed for the 10 and 5 percent tensile prestrained specimens, respectively, with the average fatigue life of 2 percent tensile prestrained specimens in between the highest and lowest average lives (fig. 2). The observed ordering in the average fatigue lives of the tensile prestrained specimens can not be predicted from cumulative damage models because they would estimate the highest and lowest fatigue lives for the 2 and 10 percent prestrained specimens, respectively, with lives of the 5 percent prestrained specimens in between the two extremes. Further investigation is needed to establish the reasons behind the observed ordering in the fatigue lives of the tensile prestrained specimens.

As mentioned earlier, all the prestrained specimens developed mean stresses of substantial magnitude. The influence of mean stresses on fatigue life is significant in the low strain range, high cycle fatigue regime, where the ratio of inelastic strain range to elastic strain range in the hysteresis loop is less than 0.1 (ref. 23). As a result, mean stresses are not expected to significantly influence the fatigue lives of prestrained specimens at the highest and intermediate strain ranges (fig. 2). However, at the lowest strain range, mean stresses can influence the fatigue lives of prestrained specimens because tensile mean stresses are usually detrimental and compressive mean stresses can be beneficial to fatigue life. The observed reduction in the fatigue lives of tensile prestrained specimens, at least to some extent, is due to the tensile mean stresses developed by most of these specimens (table III). For instance, in the low strain range, high cycle fatigue regime, the predicted fatigue lives of the tensile prestrained specimens showed improvement for all the cumulative damage models when the effect of mean stress on fatigue life was taken into consideration by the SWT parameter (figs. 3 and 5). However, in the same life regime, the predicted lives of the compressively prestrained specimens, which developed compressive mean stresses, deteriorated for all the models when the effect of mean stress on fatigue life was taken into consideration by the SWT parameter. This observation suggests that the SWT parameter overestimated the beneficial effect of compressive mean stress on the fatigue life of IN 718. Note also that the SWT parameter is inapplicable for fatigue life estimations when σ_{max} is negative. These results clearly indicate that it is necessary to characterize the effects of both tensile and compressive mean stresses on the fatigue life of IN 718 to facilitate accurate estimation of fatigue life under mean stress conditions.

CONCULSIONS

Fatigue behavior of Inconel 718 superalloy was investigated by conducting fully-reversed fatigue tests at room temperature. In addition, fatigue tests were also conducted on specimens prestrained either in tension or compression to characterize the influence of prestraining on fatigue life. Fatigue lives of the prestrained specimens were estimated by the Linear Damage Rule, the Linear Strain and Life Fraction Rule, and the Damage Curve Approach. The Smith-Watson-Topper parameter was used to determine the effects of mean stresses on the fatigue lives of the prestrained specimens.

In general, prestraining reduced the fatigue life of Inconel 718. The reduction in life was significant in the low strain range (or high cycle fatigue regime) for the specimens prestrained in tension. At the same strain range, compressive prestraining did not significantly influence the fatigue life. In general, tensile prestraining resulted in the development of tensile mean stresses during fatigue loading, which are detrimental to fatigue endurance, whereas compressive prestraining resulted in the development of compressive mean stresses, which might be beneficial to fatigue endurance.

Fatigue life predictions of the prestrained Inconel 718 by the Linear Damage Rule and the Linear Strain and Life Fraction Rule, when the effect of mean stress on fatigue life was not considered, were essentially similar and were unconservative in the high cycle fatigue regime by up to a factor of 20 compared to the experimentally observed fatigue lives. Life predictions by the nonlinear Damage Curve Approach were more accurate than those by the Linear Damage Rule and the Linear Strain and Life Fraction Rule.

All the cumulative damage rules overestimated the fatigue lives of the compressively prestrained Inconel 718 specimens in the high cycle fatigue regime, when the effect of mean stress on fatigue life was included through the Smith-Watson-Topper parameter. Fatigue lives of some of the tensile prestrained specimens were also over predicted by the Linear Damage Rule and the Linear Strain and Life Fraction Rule.

Among the cumulative damage rules investigated, the best fatigue life predictions were obtained by using the nonlinear Damage Curve Approach irrespective of whether the effect of mean stress on fatigue life was considered or disregarded.

This investigation indicated that it was necessary to experimentally characterize the effect of mean stress on the fatigue life of Inconel 718 for accurate fatigue life estimation under cumulative fatigue loading conditions.

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TABLE I.—COMPOSITION OF INCONEL 718

Element	Weight Percent
S	0.002
B	0.004
P	0.006
C	0.034
Cu	0.05
Si	0.07
Mn	0.12
Co	0.39
Al	0.57
Ti	0.95
Mo	2.87
Nb+Ta	5.19
Cr	17.52
Ni	53.58
Fe	Balance

TABLE II.—BASELINE INCONEL 718 FATIGUE DATA

Specimen Number	ν, Hz	$\Delta\sigma$, MPa	σ_m, MPa	$\Delta\varepsilon_e$, %	$\Delta\varepsilon_{in}$, %	$\Delta\varepsilon_t$, %	N_f
IN31	0.1	2168	-20	1.005	1.225	2.230	1227
IN35	0.1	2122	-23	0.984	1.148	2.132	1700
IN34	0.1	2049	-32	0.950	0.882	1.832	3115
IN33	0.1	2000	-29	0.927	0.690	1.617	4208
IN32	0.1	1888	-32	0.875	0.528	1.403	7845
IN29	0.1	1888	-28	0.875	0.398	1.273	11686
IN26	0.2	1830	-8	0.848	0.277	1.125	16040
IN28	0.2	1757	-43	0.815	0.205	1.020	34483
IN24	1.0	1680	-53	0.779	0.105	0.884	95430
IN23	1.0	1627	-14	0.754	0.036	0.790	363452

TABLE III.—INCONEL 718 FATIGUE DATA ON PRESTRAINED SPECIMENS

Specimen Number	Prestrain		Fatigue						
	e_t,%	e_{in},%	ν, Hz	$\Delta\sigma$, MPa	σ_m, MPa	$\Delta\varepsilon_e$, %	$\Delta\varepsilon_{in}$, %	$\Delta\varepsilon_t$, %	N_f
IN43	10.01	9.111	0.1	2299	74	1.066	0.969	2.035	1321
IN44	5.011	4.252	0.1	2308	48	1.070	0.945	2.015	1303
IN45	2.017	1.427	0.1	2111	-9	0.979	1.037	2.016	1776
IN52	-2.017	-1.415	0.1	2073	-53	0.961	1.096	2.057	1632
IN39	10.01	9.209	0.1	2031	-148	0.942	0.315	1.257	14648
IN46	10.03	9.190	0.1	2042	175	0.947	0.313	1.260	5984
IN40	5.011	4.264	0.1	2038	72	0.945	0.340	1.285	5644
IN41	2.011	1.379	0.1	2014	73	0.934	0.358	1.292	5969
IN51	-1.998	-1.434	0.1	1958	-94	0.908	0.392	1.300	4578
IN36	10.03	9.087	1.0	1427	-147	0.662	0.099	0.761	75027
IN47	10.03	9.166	1.0	1497	93	0.694	0.082	0.776	35145
IN37	5.029	4.222	1.0	1493	133	0.692	0.083	0.775	30752
IN20	5.005	4.205	1.0	1452	540	0.673	0.077	0.750	20273
IN38	2.004	1.403	1.0	1554	100	0.720	0.063	0.783	34684
IN21	2.014	1.379	1.0	1470	274	0.682	0.052	0.734	29600
IN50	-2.023	-1.397	1.0	1508	-217	0.699	0.077	0.776	252363
IN59	-2.017	-1.415	1.0	1518	-427	0.704	0.071	0.775	424538

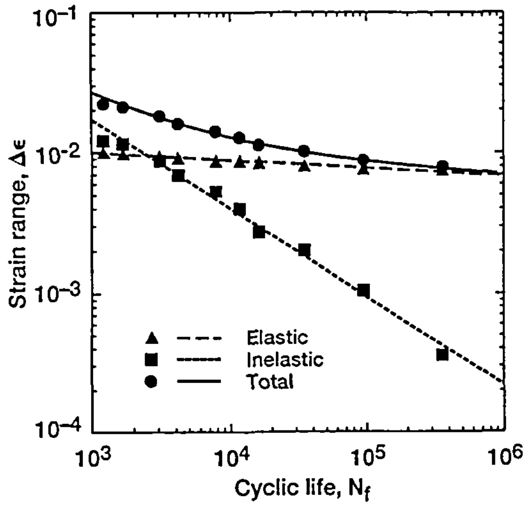

Figure 1.—Baseline fatigue life relations for Inconel 718 superalloy.

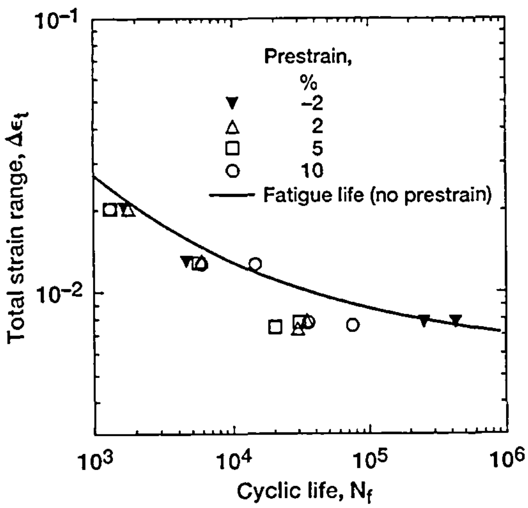

Figure 2.—Fatigue data of prestrained Inconel 718 superalloy.

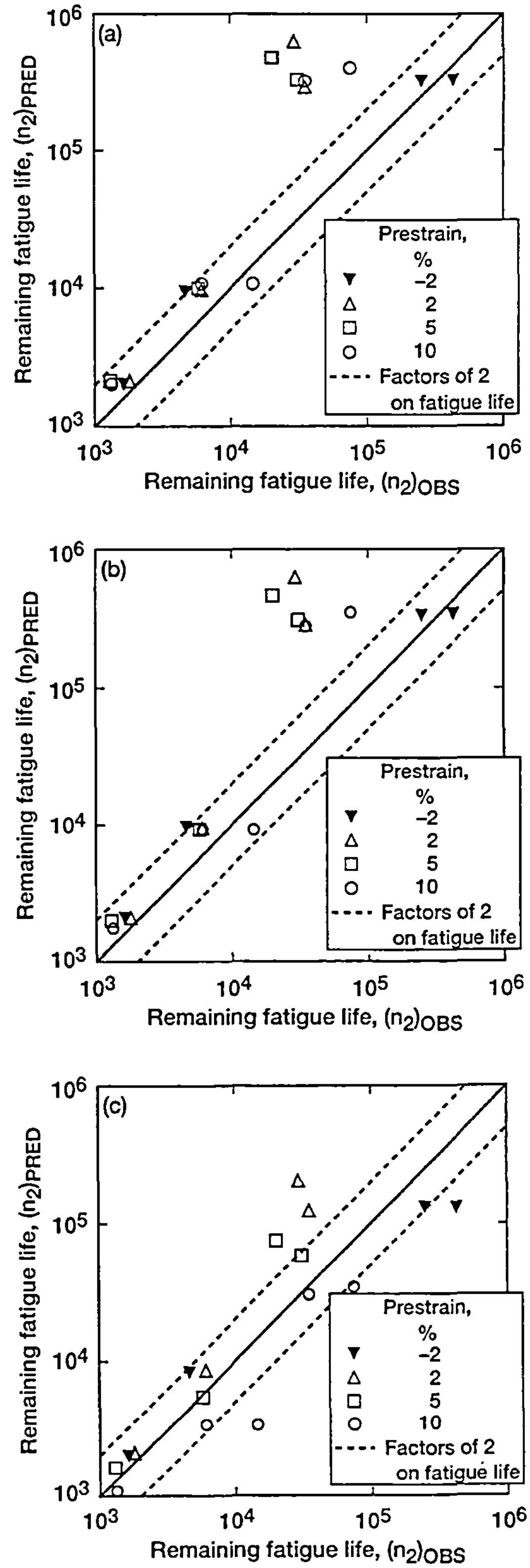

Figure 3.—Fatigue life estimation of prestrained Inconel 718 without considering mean stress effects. (a) Linear damage rule. (b) Linear strain and life fraction rule. (c) Nonlinear damage curve approach.

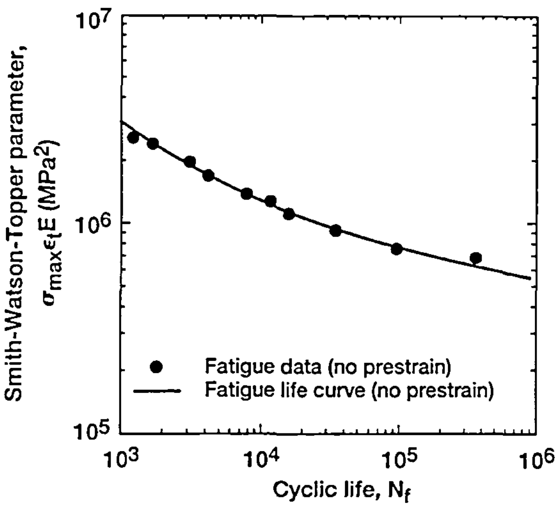

Figure 4.—Correlation of baseline fatigue data with Smith-Watson-Topper parameter.

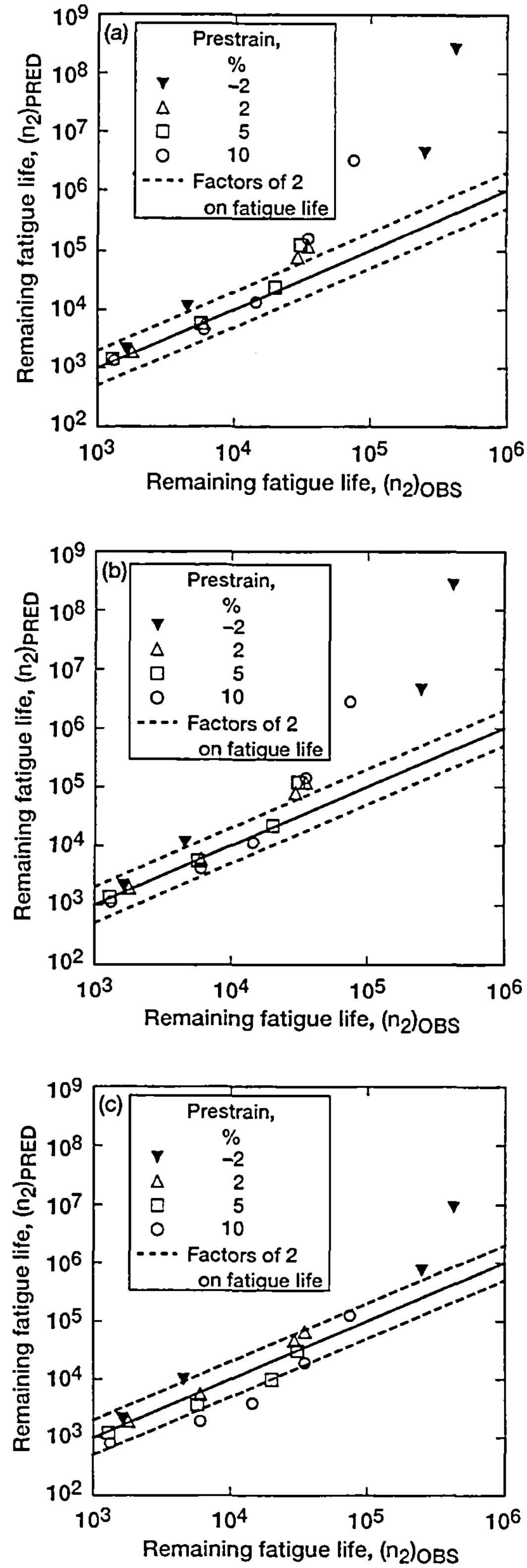

Figure 5.—Fatigue life estimation of prestrained Inconel 718 with mean stress effects. (a) Linear damage rule. (b) Linear strain and life fraction rule. (c) Nonlinear damage curve approach.

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13. ABSTRACT ***(Maximum 200 words)***

An experimental program was conducted to study the damaging effects of tensile and compressive prestrains on the fatigue life of nickel-base, Inconel 718 superalloy at room temperature. To establish baseline fatigue behavior, virgin specimens with a solid uniform gage section were fatigued to failure under fully-reversed strain-control. Additional specimens were prestrained to 2%, 5%, and 10% (engineering strains) in the tensile direction and to 2% (engineering strain) in the compressive direction under stroke-control, and were subsequently fatigued to failure under fully-reversed strain-control. Experimental results are compared with estimates of remaining fatigue lives (after prestraining) using three life prediction approaches: i) the Linear Damage Rule, ii) the Linear Strain and Life Fraction Rule, and iii) the nonlinear Damage Curve Approach. The Smith-Watson-Topper parameter was used to estimate fatigue lives in the presence of mean stresses. Among the cumulative damage rules investigated, best remaining fatigue life predictions were obtained with the nonlinear Damage Curve Approach.

14. SUBJECT TERMS

Prestraining; Metal fatigue; Cumulative fatigue damage; Mean stress; Life prediction; Nickel-base superalloy

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